Analysis of Coherent Microwave Data Collected on the Ocean over Two Decades

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LONG-TERM GOALS

The long-term goal of this project is to fully utilize microwave backscattering data sets that have been collected on the ocean over the last two decades. The prime objective is to better understand the formation of breaking waves on the ocean and their effect on microwave backscatter.

SCIENTIFIC OBJECTIVES

The scientific objectives of this research are to account for the fact that the velocities of water parcels on the open ocean observed by radar very seldom exceed 4 m/s and to relate these velocities to the occurrence of a low-frequency feature in wavenumber-frequency spectra obtained from microwave backscatter. The study may produce a new model of how breaking waves form on the open ocean.

APPROACH

Our approach is to analyze portions of data sets taken at sea with Doppler radars over the last two decades that have not previously been studied. These data sets have been taken on a variety of platforms from airplanes and towers to blimps and ships using a variety of coherent microwave radars. In the particular work that has been carried out to date, Doppler bandwidths have been plotted along with Doppler offsets and backscattering cross sections to attempt to determine where breaking was occurring. We have also looked in detail at space/time images of both cross sections and Doppler offsets of data taken on ships as well as the wavenumber/frequency spectra of these images.

WORK COMPLETED

Utilizing coherent backscatter data from shipboard radar measurements, we have produced space/time images of ocean surface velocities, or scatterer velocities, and their spectra. Figure 1 shows such an image and spectrum when the antenna was looking into the wind. The image of Figure 1a shows surface waves along with features that propagate more slowly than the waves. These features are very clear in the spectrum shown in Figure 1b where significant spectral density is observed both above and below the first-order dispersion relation. These features are commonly attributed to “groupiness” effects. We attempted to explain these higher-order features using second-order wave/wave interaction

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theory but found that the result was neither large enough nor in the same location in the wavenumber/frequency plane as the observed features. This is shown in

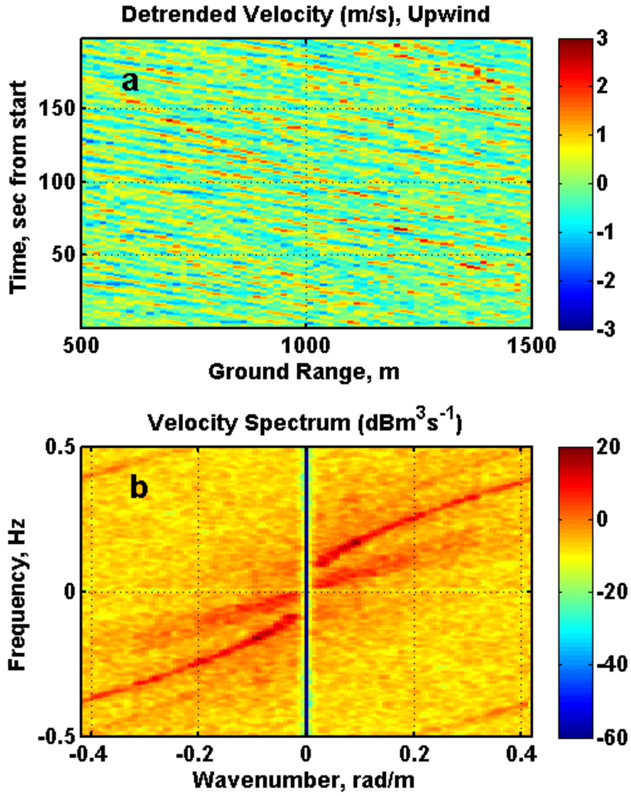

Figure 1. a) A space/time image surface velocities measured by our shipboard Doppler radar for an antenna look direction into the wind. b) The spectrum of this image showing the first order dispersion relation with other features at frequencies above and below it. Of particular interest in this report are the streaks in the image and the linear feature at low frequencies in the spectrum.

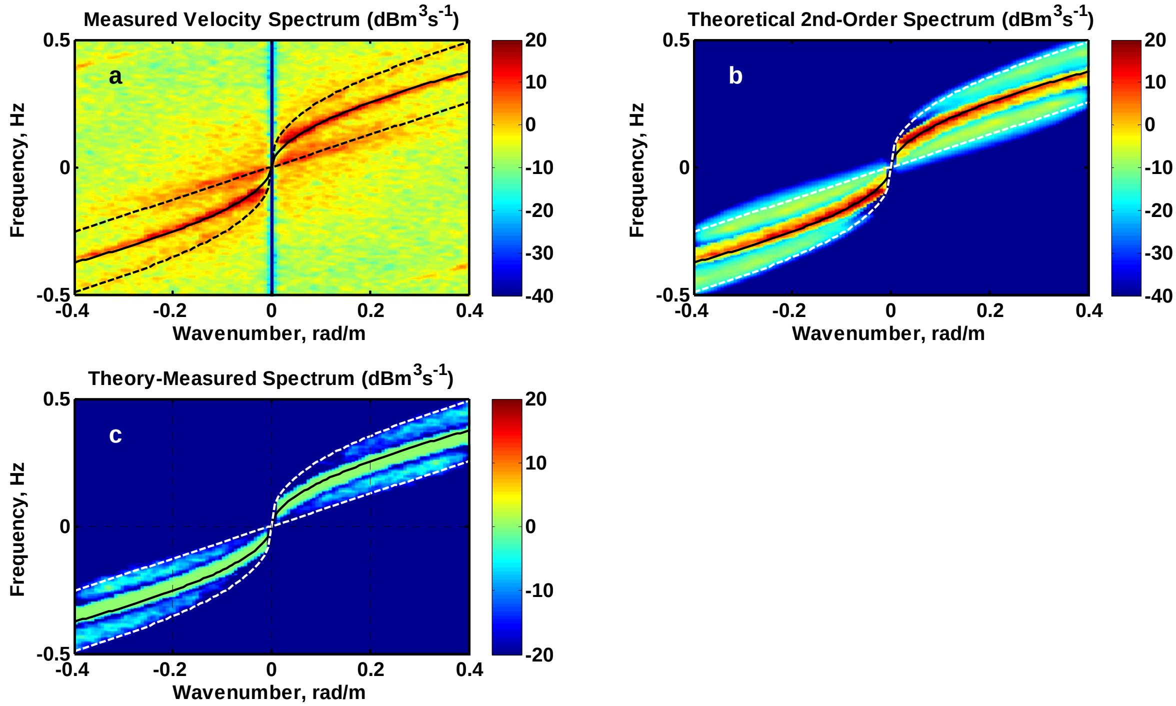

Figure 2. a) The measured wavenumber/frequency spectrum from Figure 1b. b) Features predicted by second-order wave/wave interaction theory using the measured first-order spectrum. c) The decibel difference between the second-order theory and the measurements. Second-order predictions clearly lie closer to the first-order dispersion curve than the measurements.

Figure 2 where the dashed lines are the measured locations of the features. Figures 2b and 2c clearly show that the theoretical spectra lie closer to the first-order dispersion relation than is measured.

The location of these second order features would be unchanged no matter what caused the higher order distortion of the microwave surface velocities. Thus shadowing and other distortions caused by scattering mechanisms cannot account for these features. However, swell was present during these measurements. One possibility to explain both the images and wavenumber/frequency spectra is that the swell from the west and the wind waves from the north interfere. This in itself will not produce the spectral features of interest. However, if the interference causes waves of a few meters length to break when the surface becomes steep, then features very much like those that are observed can be produced. For simplicity, we can consider a case of interfering swell and wind waves and look at the surface

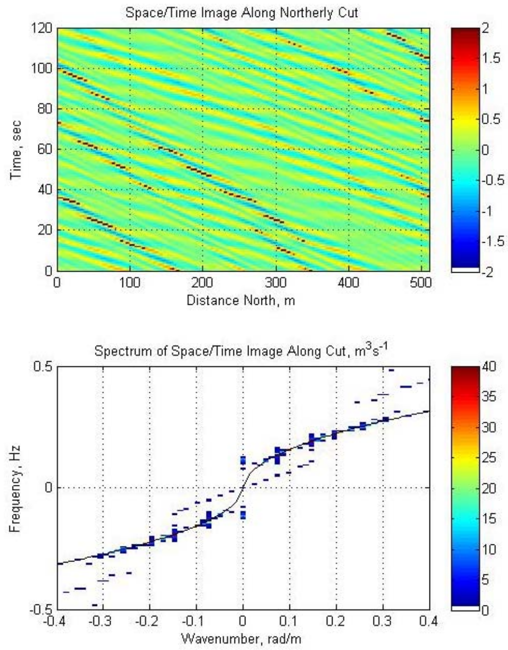

Figure 3. (top) Simulated space/time image of interfering wind waves and swell. (bottom) The wavenumber frequency spectrum of the image. Surface displacements near maxima have been increased nonlinearly.

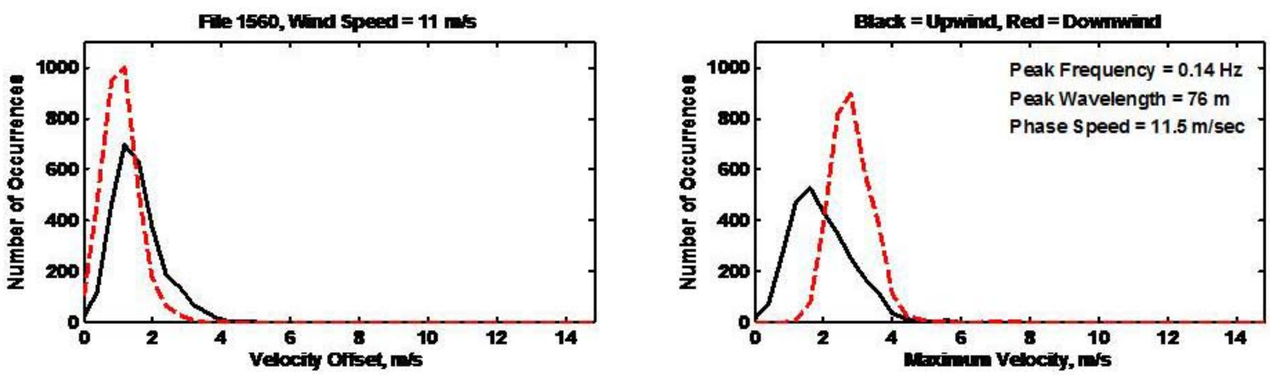

Figure 4. (left) Histogram of velocity offsets at the peak of the Doppler spectrum. (right) Maximum velocities where spectral densities of the Doppler spectrum exceeded a tenth that at the peak.

displacements when they are increased near their maxima. Although this is not quite the same as the wave breaking hypothesis, it yields the image and spectrum shown in Figure 3, which are strikingly similar to those shown in Figure 1 from the radar measurements. Notice that the slopes of the slowly moving features in the images and spectra of Figures 1 and 3 both yield a speed of about 4 m/s.

This velocity is very similar to that seen in another feature of the microwave data. The highest velocities in the Doppler spectrum measured by the radar are generally not larger than 4 m/s independent of the length of the dominant surface wave. This is shown in Figure 4 where we plot histograms of both maximum observed Doppler shifts and the Doppler offsets that correspond to the peak of the Doppler spectrum, both converted to velocities. The maximum velocities in the histograms are about 4 m/s. We are working now to understand this coincidence.

Finally, in Figure 5, we show the wavenumber/frequency spectrum when the antenna was directed perpendicular to the wind, in the direction of the swell. A low frequency linear feature still exists in this spectrum but now it travels in the opposite direction to the swell at a speed of about 1 m/s.

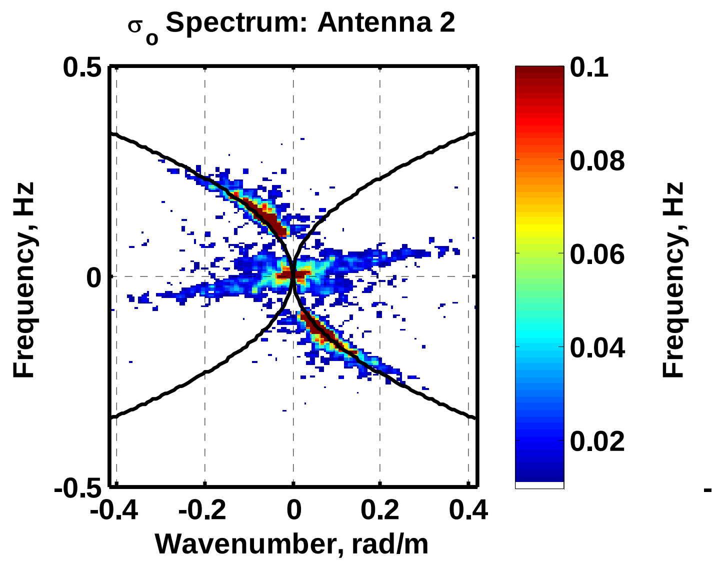

Figure 5. The wavenumber/frequency spectrum of surface velocity when the antenna was directed perpendicular to the wind in the direction of swell propagation.

This certainly cannot be explained by higher order wave/wave interactions. One possible explanation for this feature might be that wind streaks (Langumir cells) along the wind direction are moving slowly perpendicular to the wind. If this explanation is correct, then the streaks drift slowly toward the right of the wind when looking downwind.

IMPACT/APPLICATION

This work will change our understanding of the origin of the linear feature in the wavenumber/ frequency spectrum, generally called the "group line". This will point us toward a method of including second-order effects in the measurement of phase-resolved waves around a ship using radar, thus making more accurate measurements possible. Finally, this work will revise our understanding of the mechanism of wave breaking on the open ocean. Since breaking waves affect processes from ship routing to momentum, heat, and moisture transfer across the air-sea interface, the impact of this improved understanding may be appreciable.

TRANSITIONS

The results of this project have not yet been transitioned for operational use.

RELATED PROJECTS

The work carried out in this project to date is closely related to projects aimed at measuring waves around ships because it tangentially addresses the effects of second-order wave/wave interactions on retrieved phase-resolved waves. The relevant projects are ONR's Ship Guidance MURI and Hi Res DRI.